MEMOIRS

OF THE

NATIONAL MUSEUM
MELBOURNE

No. 14, Part 1

Issued May, 1944

D. J. MAHONY, M.Sc.
DIRECTOR

PUBLISHED BY ORDER OF THE TRUSTEES

MELBOURNE
BROWN, PRIOR, ANDERSON PTY. LTD., 430 LITTLE BOURKE ST., MELBOURNE C.1

PUBLIC LIBRARY, MUSEUMS AND NATIONAL GALLERY OF VICTORIA

TRUSTEES

President: Sir Keith Murdoch, kt.
Vice-President: J. F. Mackeddie, m.d., j.p.
Treasurer: R. D. Elliott, c.m.g.
M. H. Baillieu.
Rev. C. Irving Benson, d.d.
John H. Connell.
Hon. Mr. Justice C. Gavan Duffy.
Rev. W. P. Hackett, s.j.
J. J. Holland, m.l.a.
H. W. Kent.
A. E. McMicken, j.p., f.l.a.
J. D. G. Medley, m.a.
Max Meldrum.
A. Norman.
Sir David Rivett, k.c.m.g., m.a., d.sc., f.r.s., f.a.c.i.
The Hon. Wm. Slater, m.l.a.

Chief Librarian and Secretary: T. Fleming Cooke, b.a.

CONTENTS.

PAGE

Flanges of Australites. By George Baker 7

The Cranbourne Meteorites. By A. B. Edwards and G. Baker 23

An Artefact, Probably of Pleistocene Age, from Keilor, Victoria. By D. J. Mahony 37

CONTENTS

PAGE

Some unusual shapes and features of Australites (Tektites). By G. Baker 47

The Contemporaneity of the River Terraces of the Maribyrnong River, Victoria, with those of the Upper Pleistocene in Europe. By R. A. Keble and J. Hope Macpherson 52

The Sunklands of Port Phillip Bay and Bass Strait. By R. A. Keble 69

Post-tertiary Foraminifera from a bore near Rosebud, Victoria. By W. J. Parr 123

A new geographical race of *Heteronympha paradelpha* (Lower). By A. N. Burns 129

Notes on the butterfly, *Catopsilia scylla gorgophone* f. *hinda* (Butler). By A. N. Burns 131

Further Type Specimens of Shells in the Collections of the National Museum of Victoria 133

Obituary—Daniel James Mahony 134

FLANGES OF AUSTRALITES (TEKTITES).

By George Baker, M.Sc.,

Geological Department, Melbourne University.

Plates I-III.

Introduction

Flanges of australites are equatorial projections between the posterior and anterior surfaces (Fig. 1); they are broad and thick compared to the rims of some specimens, and they usually curve towards the posterior surface. Incipient flanges are called rims.

The literature of australites, which has been listed by Fenner (1938) and by Barnes (1940), contains few details of structural features of flanges. Dunn (1912 b) figured thin sections showing flow lines in the glass of which they are composed; he attributed australites to "blebs" on glass bubbles escaping from volcanoes, the flanges being part of adjacent walls of the bubbles. Fenner (1938) reviewed theories of origin and gave reasons for considering that australites are glassy meteorites and that the flanges result from flow of molten material during transit through the atmosphere; these theories are generally accepted.

The following observations are based on study of 137 flange fragments, 9 complete detached flanges, 72 fragments of australites and several complete examples. Most of the material came from the Port Campbell district, Victoria. Many thin sections were prepared.

Australites are grouped according to shape. Most of them are shaped like buttons, ovals, dumb-bells, lenses, discs, boats, teardrops, canoes and cores, but there are also aberrant forms such as "air bombs" and "crinkly tops" (Fenner, 1934).

Few flange fragments can be assigned to australites of shapes other than buttons, since few are sufficiently large to indicate the shape of the australites of which they formed a part. The majority are assumed to come from buttons because buttons are by far the most abundant type. Oval fragments are rare.

Some flanges are complete, others are imperfect owing to loss of a portion during flight or subsequently. Flanges completely

encircling australites are commonly found on buttons and more rarely on dumb-bells, ovals and boats, but flanges on dumb-bells are usually restricted to the waist and those on boats and ovals to the sides. On canoes, flanges when present are confined to the two ends, and on teardrops to the narrow end and half way along the sides. Unabraded lenses have small, sharply defined rims (Fig. 2 b) which may be considered incipient flanges. Air bombs, large cores (Baker, 1940 b) and aberrant forms are flangeless. Complete circular flanges from buttons and fragments of elongated flanges from ovals are occasionally found unattached to cores. One circular flange has been figured by Dunn (1912 a) and another by Hodge Smith (1939). On the posterior surfaces of some australites smooth bands 2 mm. to 2·5 mm. wide mark the positions from which flanges have broken away.

Fig. 1 illustrates the various parts of an australite. The chin is the rounded inner edge of the flange; the neck is the surface of the flange below the chin and facing the core, and the seat is the

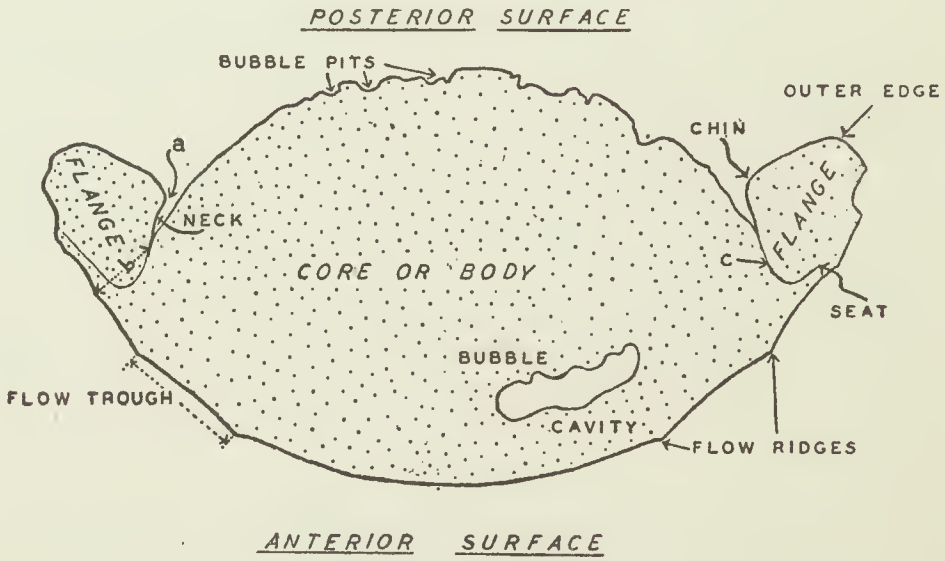


FIG. 1.

Radial Section of an Australite.

part of the core on which the flange rests. Flow ridges are ridges on the anterior surface of the core, and the spaces separating adjacent flow ridges are the flow troughs. The gap between flange and core is marked *a*; the thickness of glass between the bottom

of *a* and the anterior surface, *b*; and the junction of flange and core, *c*.

External Features

The width of flanges (distance from chin to outer edge) usually ranges from 1 mm. to 6 mm., but Hodge Smith (1939) has recorded a button-shaped australite from Mt. Cameron, Tasmania, with a 9 mm. flange. In circular and oval plate-shaped australites (Fig. 2 w and x, and Pl. I, 8 and 10) the flange forms the greater part of the specimens; those from 8 mm. to 12 mm. across have flanges 3 mm. to 5 mm. wide. Flanges are constant in width (Pl. III, 3) unless their outer edges are wavy (Pl. III, 2).

Posterior surfaces of flanges on buttons and ovals have fine, concentric flow lines in the chin region; those on most plate-shaped australites have radial flow lines. Circular or nearly circular bubble-pits and craters rarely interrupt the general smoothness of the posterior surfaces of flanges, although common on the posterior surfaces of cores. They are due to the bursting of gas bubbles at the surface as evidenced by the presence of a small blister about ready to burst on one of the flange fragments examined. Walcott (1898) suggested that the impact of small foreign bodies on semi-plastic australites caused the pits; had this been so, remnants of such postulated foreign bodies, of which there is actually no evidence, should be found embedded in the pits.

The anterior surfaces of flanges are continuous in curvature with the anterior surfaces of the cores (Fig. 1). Characteristic features are the flow ridges which are concentric or spiral (clockwise or anti-clockwise) on the cores but wrinkled on some flanges, resulting in wavy outer edges unlike the smooth inner edges of flanges. Fine, radial flow lines are most marked in the troughs of the flow waves, and they also cut through some flow ridges. Bubble-pits on anterior surfaces differ from those on posterior surfaces in being often tube-like and parallel to the radial flow lines. In some instances, they emerge from beneath flow ridges situated near the junction of flange and core. Rare circular bubble-pits on anterior surfaces consist of a crater with a small cone-shaped elevation of glass at the bottom (Pl. I, 4) suggestive of collapse under air pressure rather than of bursting by expansion.

In plan the shape of flanges corresponds with that of the australites on which they are developed, but in cross section they display considerable diversity of form (Fig. 2) and internal structure (Pl. I, 1). Fenner (1935) considered that no two

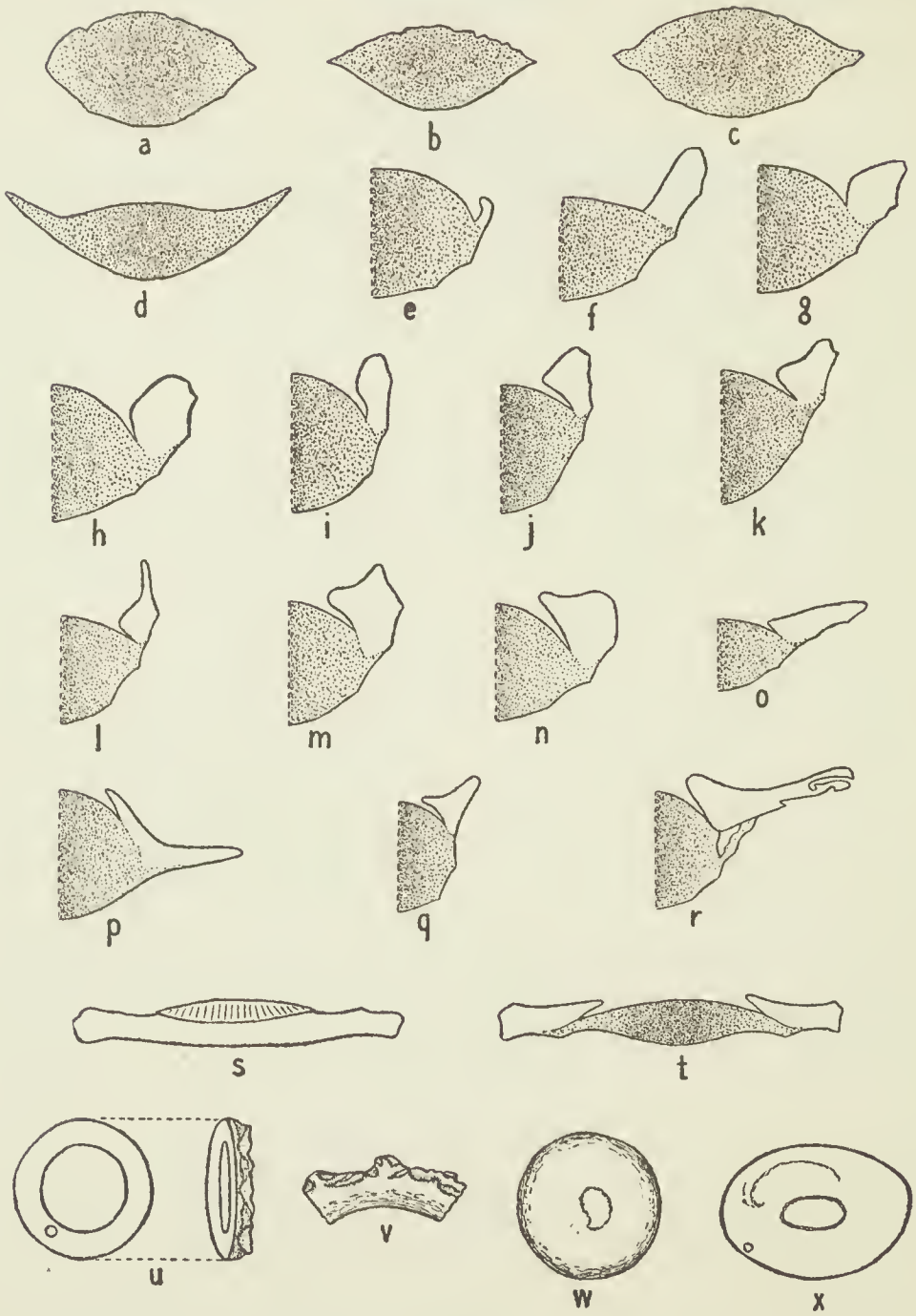


FIG. 2.

Positions and Shapes of Rims and Flanges. Posterior surfaces are shown uppermost, in a to t; u to x are sketches of posterior surfaces.

flanges are quite alike, a statement substantiated by this investigation.

Typical cross sections of flanges are indicated in Fig. 2, c to x, and a few examples were figured by Dunn (1912 b) and by Baker (1937). In Fig. 2, sketches a to n are arranged in an order which the author thinks may represent stages in development from rims of lenses (Fig. 2, a and b) through more common shapes to rare types (Fig. 2, o to t).

Fig. 2 a is a radial section of a lens with rim well marked on one side only, and Fig. 2 b a radial section of a lens with a sharply marked equatorial rim. In Fig. 2 c, a longitudinal section of an oval, the projection is intermediate between a rim and a flange. In Fig. 2 d, a longitudinal section of a canoe, the flange-like structure is further drawn out and commencing to curve posteriorly. Fig. 2 e, an oval, has a small flange partially curved towards the posterior surface of the core. The rare type illustrated in Fig. 2 f occurs on a few flat-topped buttons and on several dumb-bells and teardrops; it has a smooth rounded outer edge and marked flow ridges, and is inclined at 60° to the central core. Fig. 2 g, a cross section of the flange of a button, has a vertical neck and a flat posterior surface inclined at 20° from the horizontal and the gap (*a* in Fig. 1) is becoming conspicuous; button-shaped australites from Mulka, South Australia, commonly have flanges of this type, but at Port Campbell only certain boat-shaped specimens have such flanges.

Fig. 2, h and i, flanges of buttons, illustrate convex posterior surfaces partially overlapping towards the core, and Fig. 2, j to r, show further stages of rearward curvature but may not represent a definite series of stages. Overlapping may reach a stage where the contact between flange and core is completely obscured from above.

Fig. 2 s, a radial section of an oval, plate-shaped australite (plan like that of Fig. 2 x) shows a thin, flat horizontal flange with shallow depressions between the centre and the outer edges of the anterior surface. In Fig. 2 t, a radial section of a flat, disc-shaped australite (plan like that of Fig. 2 w), the flange overlaps a thin central core. Fig. 2 u, plan and side aspect of a detached flange, shows that the width of the flange is considerably less than the diameter of the area once occupied by the core. Fig. 2 v is a flange fragment with a smooth inner edge and adjacent flow lines, and a crenulate outer edge. In Fig. 2 w, a disc, the flange is broad in proportion to the core and has concentric flow lines near its outer edge. In Fig. 2 x, the posterior surface of an oval, plate-shaped

australite, the flange is broad, and carries few flow lines and one bubble-pit.

On an oval, bowl-shaped australite figured by Baker (1940 a) a rare type of flange forms the sides and the small core the base of the bowl. In this specimen, probably a flat and thin flange was pushed backwards while plastic by atmospheric pressure.

Internal Structures

Internal structures of flanges and cores are intimately associated. They are best seen in thin plates, although distinct on weathered surfaces of fractured specimens and on artificially polished surfaces etched with a mixture of strong sulphuric and hydrofluoric acids. In thin plates the Becké line effect clearly reveals the complexity of the flow patterns.

After australites arrived at the earth's surface, internal cracks (probably resulting from stresses set up during cooling) were infilled with ferruginous clay containing occasional grains of quartz (Pl. I, 2); similar material sometimes also infills the gap *a* and some bubble-pits. The cracks may traverse both flange and central core, sometimes cutting across the surface of union *c* from the gap *a* and bifurcating in the base of the flange (Pl. III, 1 and 4). They cut across internal structures without offsetting them.

The refractive indices of the flange glass of two australites from Port Campbell, of specific gravity 2·409 and 2·410, were found by the immersion method to be 1·510 and between 1·505 and 1·510 respectively. The glass is isotropic except for occasional bands of higher refractive index (1·535) which sometimes exhibit strain polarization. Such bands are especially noticeable near the junction of flange and core and in contorted structures of flanges. Optical figures for these strained areas are too indefinite for accurate determination, although some appear to be biaxial. Strained areas are often colourless, the remainder of the glass being pale yellowish-green in thin plates except where colour banding imparts a deeper brownish colour (Pl. II, 1 and 9).

Inclusions

The only inclusions in flanges and central cores are gas bubbles and minute glassy particles (Fig. 3).

The bubbles are frequently circular, but may be elliptical along flow directions. All bubbles in flanges are minute, but in the central cores they may be larger and segmented (Pl. I, 12) or

may even occupy the bulk of the interior, as in a hollow sphere from Hamilton, Victoria, described and figured by Dunn (1912 b). In thin plates, all the smaller bubbles have dark borders. Barnes (1940) regarded similar spherical bubbles in tektites (bediasites) from Texas, U.S.A., as formed later than flow structures; but in australites elongated bubbles and flow structures bending round spherical bubbles indicate that bubbles were formed prior to flow. It is therefore likely that bubbles continued to form throughout the development of australites, and that bubbles with dark borders are primary. Small secondary cavities lacking dark borders are confined to posterior surface regions of the core near its union with the flange; they were originally pits, but some are either infilled with or partly enclosed by glass from the flange (Pl. II, 8 and 11, and Pl. III, 5 and 7). In thin plates such infilled cavities are delimited by differences between the refractive index of the walls and that of the infilling glass. Infilled cavities are sometimes tubular with rounded bases and with openings to the posterior surfaces of the cores, as shown by some of the dark areas (infilled with ferruginous clay) in Pl. II, 5.

Most bubble-pits are semi-circular in section (Pl. I, 1 and 12, and Pl. III, 7), but a few are tube-like or funnel-shaped. In sections of cores numerous bubble-pits in close proximity give rise to jagged outlines in sections through the posterior surface (Pl. I, 7).

Bubble-pits are rarer on anterior than on posterior surfaces. Many pits on anterior surfaces are wider at the base than at the opening, and they may have a central pyramid of glass (Pl. I, 4); some of the larger pits are irregular in shape (Pl. I, 5).

The minute glassy particles (Fig. 3) are microscopic in size, pale pink where embedded in glass, but colourless where protruding, and their refractive index (1·460) is lower than that of the surrounding glass (1·510). They are numerous in those parts of flanges contorted by flow structures, but are also common along line of union *c*; infrequent in central cores and scarce in the less disturbed regions of flanges. They form rounded or irregularly-shaped blebs, granules, elongated threads, and ribbons. Ribbon and thread-like particles may be coiled and contorted (Fig. 3, A, B and L), some only slightly (Fig. 3, C and K), others in complex fashion like examples from bediasites figured by Barnes (1940). Some associated with flow directions are elongated, others are neither distorted nor elongated. Occasional bleb-like particles are hooked (Fig. 3 E), curled (Fig. 3 G) or bean-shaped (Fig. 3 F), and some are lens-shaped particles with tapered plane spiral processes (Fig. 3 I). Some granular particles

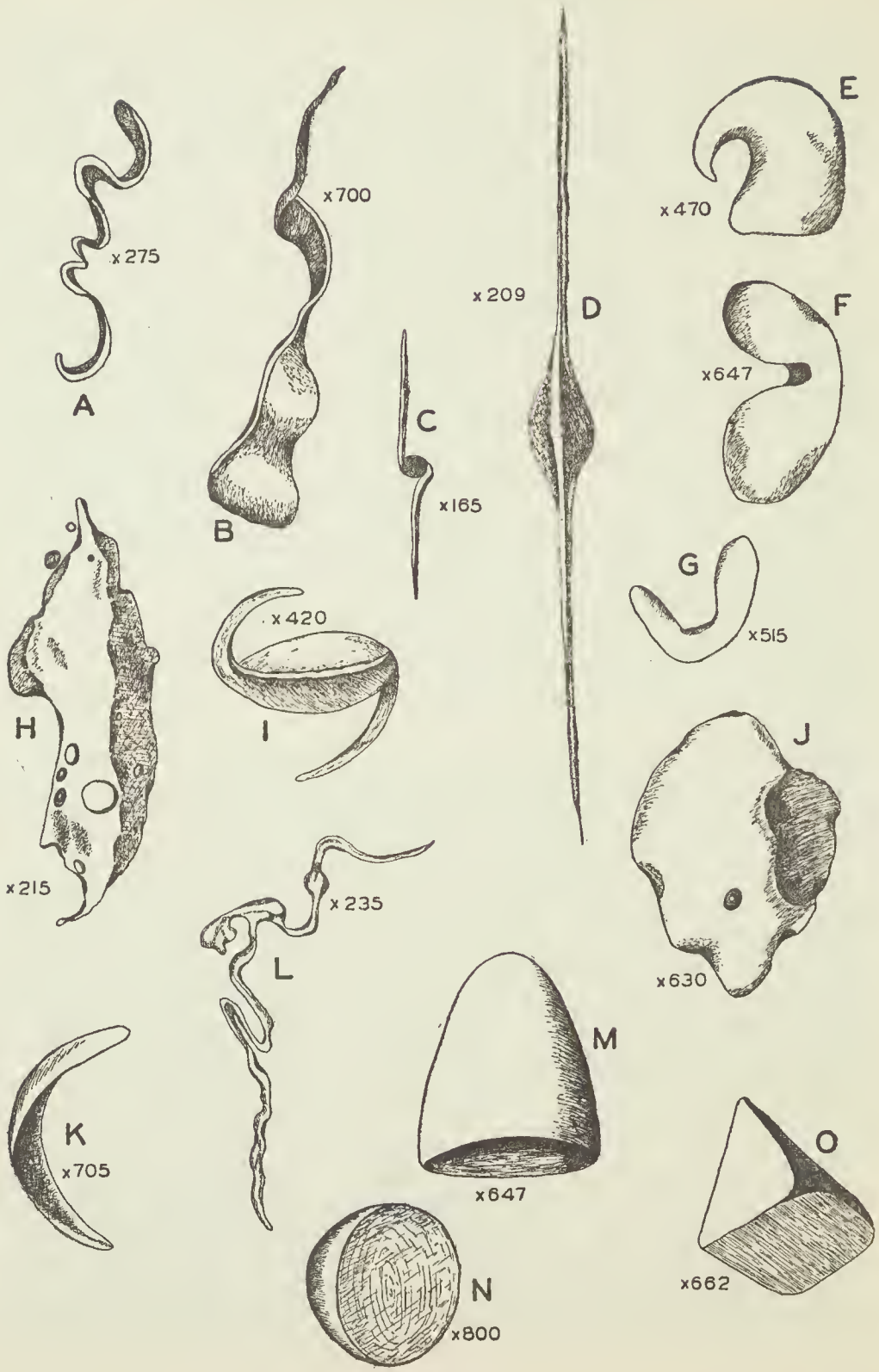


FIG. 3.
Glass Inclusions.
(All observed in radial sections of flanges except M.)

have facetted surfaces (Fig. 3 O). Irregular flint-like particles (Fig. 3, H and J) are often associated with gas bubbles within their own substance and in the surrounding glass. Many bubbles were probably released during the formation of these particles. Other particles are ellipsoidal, some with flattened bases (Fig. 3 M). The majority of those along the surface of union *c* are hemispherical (Fig. 3 N); they are embedded in the cores, and have their flat bases in contact with and parallel to *c*.

Most of these particles are isotropic, but occasional irregularly-shaped examples (Fig. 3 H) are birefringent and give polarization colours of a low order but no axial figures; some such particles are surrounded by a halo of glass with a refractive index intermediate between that of the normal glass and that of the particles; these haloes are usually isotropic, but a few are birefringent and give low polarization colours.

Barnes (1940) regarded similar inclusions in bediasites (Texas) and other tektites as lechatelierite, i.e., re-fused quartz akin to the material of fulgurites; he suggested that they indicate either limited liquid miscibility or, more probably, incompletely mixed re-fused quartz grains of the material from which the tektites were formed. For this reason he suggested that tektites may be of fulguritic origin; but similar inclusions have been observed by the author in Pelée's Hair from Kilauea, in Darwin Glass from Tasmania, and more rarely in fulgurites from Macquarie Harbour, New South Wales.

The origin of these particles may be the key to that of tektites.

Flow Structures

Internal flow structures in cores and flanges are very pronounced (Pl. I to III). Many near the posterior surfaces lead to the bases of bubble-pits (Pl. II, 6 and 8), suggesting directions of internal gas streaming, but elsewhere they are associated with streaks of glass showing strain polarization, differences in refractive index, or both, and with elongated partially resorbed glassy inclusions. It therefore appears that flow lines result partly from escape of gas through the posterior surfaces and partly from flowage of molten glass. Directions of streaming are more readily determined in flanges than in cores. In flanges the spiral and elliptical structures are seen to best advantage on fractured surfaces (Baker, 1937, Figs. 1-7) and in radial sections (Pl. I, 8 and 10, and Pl. II). In equatorial sections of flanges these structures are concentric (Pl III, 3 and 6), but within cores most of them are complex, their major directional trends

being sometimes towards posterior surfaces (Pl. I, 6) but more frequently along anterior surfaces towards equatorial regions. Some main flow lines well within the body are parallel to its exterior surfaces (Pl. I, 9), others are radial (Pl. I, 1). Those near anterior surfaces arise in all positions from the front pole almost to the flange junction, *c*, numerous short flow lines originating within the body at depths below the surface of from 0·5 mm. at the junction *c*, up to 3 mm. near the front pole; these unite and form streaks trending more or less parallel to the anterior surface. Near and parallel to the posterior surfaces main sets of flow lines are rare (Pl. I, 5), and they seldom trend from both anterior and posterior surfaces towards equatorial regions (Pl. I, 3). Flow lines close to anterior surfaces are generally truncated in flow troughs, but are parallel with those in flow ridges (Pl. III, 1); this indicates some loss of glass in such regions, probably caused by ablation during flight.

Oblique sections across the line of union *c* (Pl. III, 5) also show internal flow lines in the core trending mainly flange-wards, but made complex by fold-like structures. Most of the complex flow lines within cores were probably formed at an earlier stage.

Union Between Flange and Core

Surfaces of attachment between flanges and central cores (*c*, Fig. 1) can be seen on detached flanges free from adhering portions of core. Tracks of bubbles and aggregations of bubble-pits indicate accumulation of gas in this region; this must weaken the attachment of flange to core and it accounts for the occurrence of detached complete flanges.

The surface of the neck often carries concentric flow lines parallel to similar lines on the chin.

In thin section *c* is invariably a sharp, dark line; and, as already remarked, small bubble-pits tend to assemble at or near it (Pl. II, 8 and 11, and Pl. III, 7). Before reaching the anterior surface, *c* usually swings round parallel to the anterior surface (Pl. II, 3), ultimately passing into the flange as flow lines; it thus marks off the seat (Fig. 1), a narrow, shelf-like part of the core upon which the flange rests. Flow structures in the base of the flange are parallel to those of the seat (Pl. II, 4). The seat may be small (Pl. II, 8 and 10) or almost wanting (Pl. II, 1 and 9), probably as a result of ablation during flight. The width of glass at *b* (Fig. 1) ranges from 2 mm. to 6 mm. At the wider end of the seat the glass is from 0·5 to 1 mm. thick.

Australites with small seats associated with plentiful bubbles would lose their flanges more readily than would other forms.

Specific Gravity and Composition

The specific gravities of 107 flange fragments and three complete detached flanges from Port Campbell range from 2·31 to 2·44, the average being 2·385; the average for cores is 2·426, range 2·34 to 2·49 (Baker and Forster, 1943). The difference in the mean values, 0·04, suggests that flanges are more acidic than central cores, since the specific gravities of australites rise as their silica content decreases. This is borne out by specific gravity determinations of the powders of flange and core of two australites from Port Campbell; the specific gravity of the core of a boat-shaped specimen is 2·34, that of its flange is 2·29; for a button-shaped specimen, the specific gravity of the core is 2·33, that of its flange 2·29.

Variation in composition within some flanges is also indicated by colour banding and by differences in refractive index. Bands coloured deep brown in thin sections are evidently richer in iron than the surrounding pale green glass.

Origin of Shapes and Structures

According to Dunn's bubble hypothesis (1912 b), the glass of australites flowed downwards from the top (posterior) towards the bottom (anterior) surface. It is now, however, generally accepted that the movement of molten glass was from the anterior surface towards the equatorial region (Fenner, 1934).

Dunn thought that the flanges were not sufficiently hot to coalesce with the cores along the junction *c* (Fig. 1). In some instances, they must, however, have been sufficiently hot because (a) some bubble-pits on the posterior surface of the core have been re-enclosed by the glass of the flange, and (b) in "crinkly-top" types (Fenner, 1934) melted glass spread over portions of posterior surfaces. In general, the material of the flange solidified before coming into complete contact with the glass of posterior surfaces of cores, leaving the gap *a* (Fig. 1).

According to the hypothis of meteoric origin, the front surface in australites was melted by heat generated by friction of the air (note by Suess, in Fenner, 1935) or was already molten when shed from a burning light-metal meteorite. Under pressure by the atmosphere this molten glass flowed towards the equatorial region and formed the flange; some molten glass was lost during flight, however, as evidenced by truncated flow lines in the flow troughs. The congealing glass of the flange was forced back by pressure and frictional drag, and was partially rolled in upon

itself, and the flow structures frequently indicate spiral coiling of the flange glass.

The complex flow patterns in flanges result from the movement of cooling glass from the outer edge towards still cooler glass in and below the chin. The major flow structures result from flowage from the anterior surface of successive streams of molten glass; see Plates I to III.

The shapes of australites are not those considered as streamlined by physicists, but no other tektites approach a similar degree of symmetry, a fact suggesting that these tektites differed from australites in physical condition during transit through the atmosphere.

If australites traversed our atmosphere at speeds greater than that of sound, the adjacent layers of air in which all frictional effects took place would be thin. Since the coefficient of heat conductivity in australite glass is low (somewhere between that of artificial glass, 0·0005, and that of Darwin Glass, 0·0002), the rate of heat transference is slow. Little time was available while the australites traversed the atmosphere for diffusion of heat to the interior and to rear surfaces. To become plastic the glass must be raised to temperatures of 800°C. or higher. In the wake of fast-moving australites there would be a region of "dead air" where pressures and temperatures were low, and the rear regions of the objects would therefore remain cold.

It has been shown experimentally that no frictional forces operate at the poles of a sphere falling through a fluid, that pressure is greatest at the front and least at the rear pole, and that frictional forces are greatest at the equator. It is therefore probable that, during flight, pressure on the anterior surfaces of australites caused plastic glass to form ridges which moved towards their equators, where these ridges would be crinkled by frictional drag developed by turbulences in the adjacent layer of air. Flow lines would therefore be contorted or puckered near the outer edge of the flange (Pl. I, 12, and Pl. II, 3 and 7). On reaching the outer edge of the flange, some of the plastic glass was swept towards the posterior surface, probably by eddy currents which exerted a smoothing effect, as indicated by the smooth posterior surfaces of flanges. Complexities in internal structures of flanges, then, resulted from variations in direction of eddy currents and in the rate of cooling of successive layers of molten glass. The first supplies of glass to a growing flange would cool while more fluid glass was flowing in from the heated front surface.

Velocity of flight probably controlled the limiting height of flow ridges on forward surfaces; in the final phase of flight, these heights were at a maximum of 1 mm., and the distances between the ridges reached a maximum of 3 mm. to 4 mm. nearest the front pole.

Only translatory motion is here considered, since rotary movements must greatly complicate motions in the boundary layers of air and their effects.

At supersonic speeds, if the motion of the solid is purely translatory, a disturbance of a permanent type would be set up in the shock waves of air ahead of the australites. Such shock waves are considered as sheets in which there is discontinuity of velocity and they travel in front of the body producing them at the same speed and in the same direction as that body (Durand, 1935). At all other points the shock waves move obliquely to the direction of flight (cf. bullet in motion, illustrated by Durand, 1935). Wavelets are formed in the air layer in contact with the australite wherever there are irregularities (e.g., flow ridges perhaps) upon the curved forward surface. Pressure increases in such regions during separation of the main air-stream from boundary layers, i.e., between points of origin of the shock wavelets, causing within these areas differential dragging of small amounts of plastic glass with the result that flow lines are truncated in the flow troughs.

Reverse and secondary reverse flows in the boundary layers of air caused whirlpools or vortices about the equatorial regions, where the main flow of air diverged from the bodies. These vortices generated stresses that caused complex puckering of surface structures in thin films of plastic glass. The stretching, bending and twisting of glassy particles in the flanges resulted from (a) turbulency in the plastic glass moving back under pressure to form the flange and (b) jamming during the development of the flow structures in the glass.

The total drag on forward surfaces is set up both by pressure and by friction; these are functions of the shape and surface areas of the bodies. Conversion of mechanical energy into heat is due to the viscosity and conductivity of the air; viscosity and conductivity are also regarded as maintaining shock waves of a permanent type (Durand, 1935). The concentric flow ridges on forward surfaces of certain australites are in keeping with such shock waves and wavelets; and since these can be caused only by non-rotating bodies, the inference is that australites with concentric flow ridges did not rotate during flight through the atmosphere.

Spiral flow ridges were probably caused by combined rotary and translatory motions; these involve complications far beyond the scope of this article.

Acknowledgments

My thanks are due to D. J. Mahony, Director of the National Museum, for helpful criticism of the manuscript and to J. Spencer Mann, Geology Department, Melbourne University, for taking the excellent photographs used in the Plates.

References

Baker, G., 1937. Tektites from the Sherbrook River District, East of Port Campbell. Pr. R. Soc. Vict., 49 (n.s.), pt. 2, pp. 165-77, 2 figs.

1940a. An Unusual Australite Form. *Ibid.*, 52 (n.s.), pt. 2, pp. 312-14, 1 fig.

1940b. Some Australite Structures and their Origin. Min. Mag., 25, pp. 487-94, 1 fig., 1 pl.

Baker, G., and H. C. Forster, 1943. The Specific Gravity Relationships of Australites. Amer. Journ. Science, 241, pp. 377-406, 9 figs.

Barnes, V. E., 1940. North American Tektites. University of Texas Publication No. 3945, pp. 477-656, 17 figs., 5 pl.

Dunn, E. J., 1912a. Pebbles. Robertson & Co., Melbourne, pp. 30, 34, 45, 63 and 64, pl. 57 and 58.

1912b. Australites. Bull. Geol. Surv. Vict., 27, pp. 21, 17 pl.

1916. Additional Notes on Australites. Pr. R. Soc. Vict., 28 (n.s.), pt. 2, pp. 223-27, 1 pl.

Durand, F. W., 1935. Aerodynamic Theory, vol. 3. Julius Springer, Berlin, pp. 212-243, figs. 26-31.

Fenner, C., 1934. Australites, Part 1. Classification of the W. H. C. Shaw Collection. Tr. R. Soc. S. Aust., 58, pp. 62-79, 4 figs., 6 pl.

1935. Australites, Part 2. Numbers, Forms, Distribution and Origin. *Ibid.*, 59, pp. 125-140, 3 figs.

1938. Australites, Part 3. A Contribution to the Problem of the Origin of Tektites. *Ibid.*, 62, pt. 2, pp. 192-216, 3 figs., 2 pl.

Smith, T. Hodge, 1939. Australian Meteorites. Mem. Aust. Museum, Sydney, 7, pp. 65-70, pl. 19.

Walcott, R. H., 1898. The Occurrence of so-called Obsidian Bombs in Australia. Pr. R. Soc. Vict., 11 (n.s.), pt. 1, pp. 23-53, 2 pl.

Explanation of Plates

Plate I

Fig. 1. Radial section of button-shaped australite showing turbulent flow patterns in the core and variations in pattern in the two portions of the flange. Flow lines from anterior surface of core pass upwards into flange.

2. Radial section of button-shaped australite. The dark irregular bands are cracks infilled by ferruginous clay containing quartz grains.

3. Cross section of boat-shaped australite with well-marked rim. Internal flow lines near anterior surface truncated in flow troughs at right hand end.
4. Tangential section of button-shaped australite; ferruginous clay (black) fills the gap *a*. A bubble crater on anterior surface has a central pyramid of glass. Neck of flange vertical.
5. Longitudinal section of oval australite. Flow lines parallel to posterior surface. Remnants of former flange (top right). Flow lines trending from both posterior and anterior surface regions into a new flange. Irregular bubble cavity on anterior surface.
6. Radial section of lens-shaped australite showing directions of major flow lines trending from anterior to posterior surfaces. Rim poorly developed.
7. Radial section of lens-shaped australite with bubble crater on anterior surface; jagged outline of posterior surface due to numerous bubble-pits. Flow pattern complex but flow lines in equatorial regions trend towards rim.
8. Cross section of oval, plate-like australite showing spiral flow lines in flange. Flange and core separated by well-marked line of union *c* from which bubbles are nearly absent. Complex flow pattern in core. Truncation of flow lines in left hand portion of flange probably due to ablation.
9. Longitudinal section of boat-shaped australite showing flow lines partially parallel to its length. Rim pronounced at left hand end; abrupt termination of structures at other side probably due to loss by ablation.
10. Cross section of oval, plate-like australite with spirally coiled flow lines in flange. Small bubbles (dark areas) along the line of union *c*.
11. Longitudinal section of canoe-shaped australite showing flange-like ends curving away from anterior surface, and flow lines trending from the body into this structure.
12. Cross section of button-shaped or oval australite showing segmented bubble cavity. A crack passes from posterior almost to anterior surface. Internal flow lines truncated in flow waves on anterior surface. In flange, flow lines in posterior surface regions are contorted in concertina fashion.

Plate II

Radial sections of flanges.

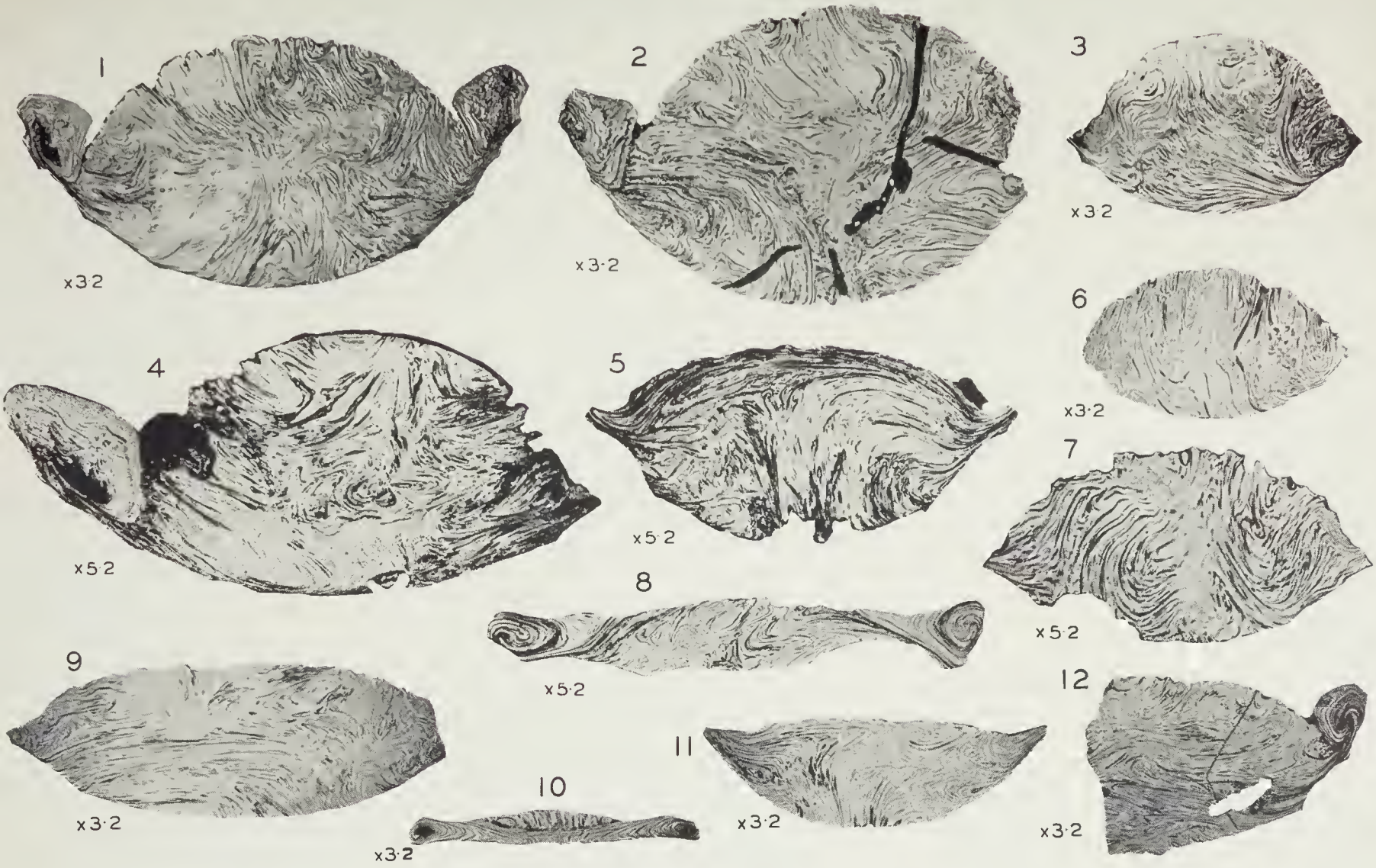
Fig. 1. Line of union *c* sharply defined. Colour bands (darker areas in the chin region) parallel with the flow lines. Seat wanting.
2. Line of union *c* short, seat separated from base of flange. Flow lines in anterior surface regions of core continuous with those in seat. Flow groove in outer edge of flange.
3. Line of union *c* well marked; flow troughs well defined on anterior surface of flange; seat continued well up the flange. Concertina-like flow lines in chin regions of flange.
4. Flow lines near outer edge of flange coiled into a plane spiral, those in chin regions normal to outer surface. Accumulations of bubbles at line of union *c* shown by dark areas on core side. Flow lines of seat truncated in flow trough.

5. Gap *a* filled with ferruginous clay (dark area). Bubble tubes (black areas) along line of union *c* continuous with flow lines in core.
6. Flow lines parallel in seat, folded towards posterior side of flange and contorted in vortical region (dark). Neck inclined; posterior surface of flange flat.
7. Flow lines in seat continuous with those in anterior surface regions of core; those in flange deeply folded on posterior side of the vortical region. Flow lines in core normal to posterior surface.
8. Re-enclosed bubble-pits in core occur along the line of union *c*. Flow lines in core have marked trend towards bases of bubble-pits opening on its posterior surface. On flange, vortical region of spirally coiled flow lines lacking, probably removed by ablation.
9. Sharp line of union *c* without bubbles. Seat structure ill-defined. Colour banding represented by darker regions in chin and along line of union *c*. Posterior surface of flange concave.
10. Seat small. Line of union *c* clearly defined, not associated with bubbles. Flow lines normal to surface in chin, line of union *c*, and base of flange. Flow lines spirally coiled in outer edge regions; vortical portion of coiling clearly marked.
11. Re-enclosed bubble-pits along line of union *c*; seat sharply terminated at lowest flow ridge in flange; ferruginous clay infilling gap *a*. Posterior surface of flange concave with outer edge reduced in thickness by ablation.

Plate III

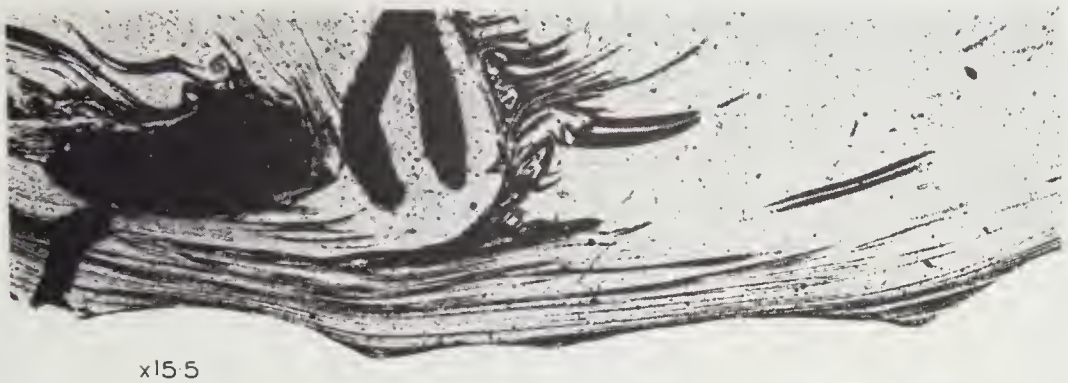
Fig. 1. Enlarged portion of Fig. 4 (this Plate). Spiral coiling in vortical region (black area) obscured by crowding. Flow lines of anterior surface truncated in the flow troughs. Tubes of glass of different refractive index occur in core near line of union *c*.

2. Equatorial section of flange fragment. Outer edge crenulate, inner edge smooth. Flow lines in chin region concentric and parallel with the inner edge; in other parts crowded and confused.
3. Equatorial section of half a flange. Both inner and outer edges relatively smooth. Flow lines locally complex, but major trends parallel with the outer and inner edges.
4. Radial section of flange on button-shaped australite, showing bifurcating crack infilled with ferruginous clay extending from gap *a* into base of flange. Flow lines pass from anterior surface regions of core into seat and coil spirally near outer edge.
5. Oblique section through junction of flange and core of button-shaped australite. Re-enclosed bubble-pits along line of union *c*. General direction of flow lines in flange parallel to *c*.
6. Equatorial section of disc-shaped australite (cross section as in Plate I, Fig. 8) showing broad flange with concentric flow structures and small core with bubble cavity and complex flow pattern.
7. Equatorial section of button-shaped australite with remnants of flange, showing re-enclosed bubble-pits along line of union *c* and complex flow pattern in core.



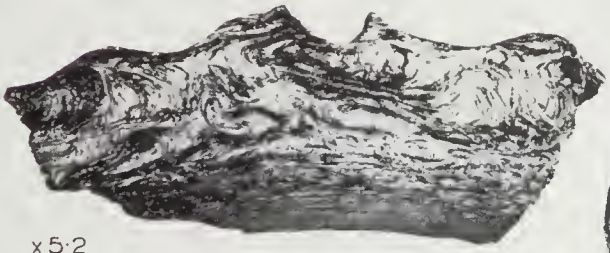
Flanges of Australites

Flanges of Australites



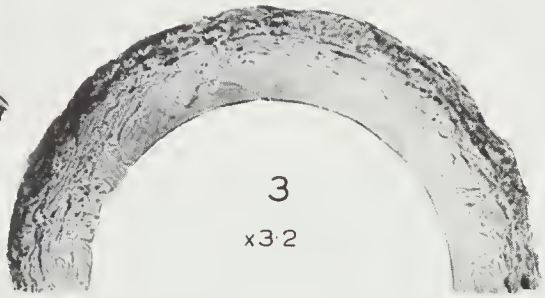
x15·5

1



x5·2

2

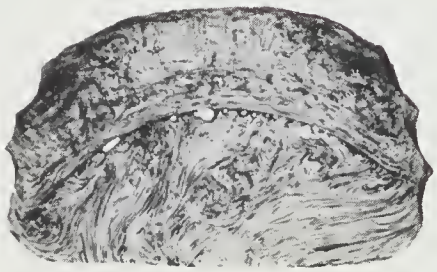


3

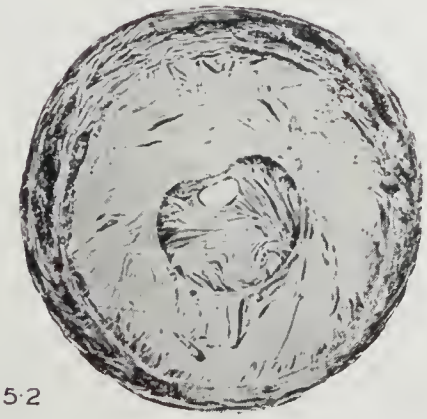
x3·2

x9

4

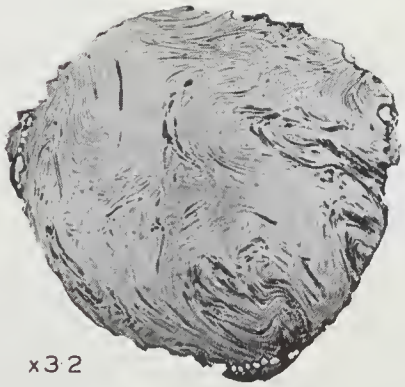


5 x3·2



x5·2

6



x3·2

7

Flanges of Australites

THE CRANBOURNE METEORITES.

By A. B. Edwards, D.Sc., and G. Baker, M.Sc.,
Geology Department, Melbourne University.

Plate IV.

The object of this paper is to describe the four Cranbourne iron meteorites found in 1923, and to co-ordinate published records concerning them and the earlier found Cranbourne meteorites. The Cranbourne meteorites, including the four described here, comprise a group of ten closely related irons exceeding 10 tons in weight that appear to have been derived from the breaking up during flight of a single large mass of iron when close to the earth's surface. This view was proposed by Walcott (1915), who showed that the sites of the five irons then known lay along a straight line trending S. 30° W. from Beaconsfield to Langwarrin. His conclusion is greatly strengthened by the fact that the sites of the four Cranbourne irons found in 1923 and the Pakenham iron (Edwards and Baker, 1941) found in 1928 conform closely to this line.

The Cranbourne Irons

Five of the iron meteorites were found prior to 1886. Four more were found in 1923, and one in 1928.

The first to be found, the famous Cranbourne No. 1, was discovered in 1854 on the Carnmallam Pre-emptive Right, in allotment 39, parish of Sherwood, 3½ miles south of Cranbourne township (Fig. 1). It weighed 3·5 tons, and is the largest meteorite to have been found in Australia. Its discovery evoked world-wide interest, and about sixty papers have been published concerning it and the other four of the group found prior to 1923, namely, the Cranbourne No. 2, Cranbourne No. 3, the Beaconsfield and the Langwarrin irons. Lists of the publications are given by Walcott (1915) and by Hodge Smith (1939). The Cranbourne No. 1 is now in the British Museum.

The Cranbourne No. 2 iron, which weighed 1·5 tons, was found in the same year as the Cranbourne No. 1. It is the second largest of the Cranbourne irons, being 37 in. x 32 in. x 21 in. It was found in allotment 39, parish of Cranbourne, 2 miles east of Cranbourne township (Fig. 1), and is now in the National Museum, Melbourne.

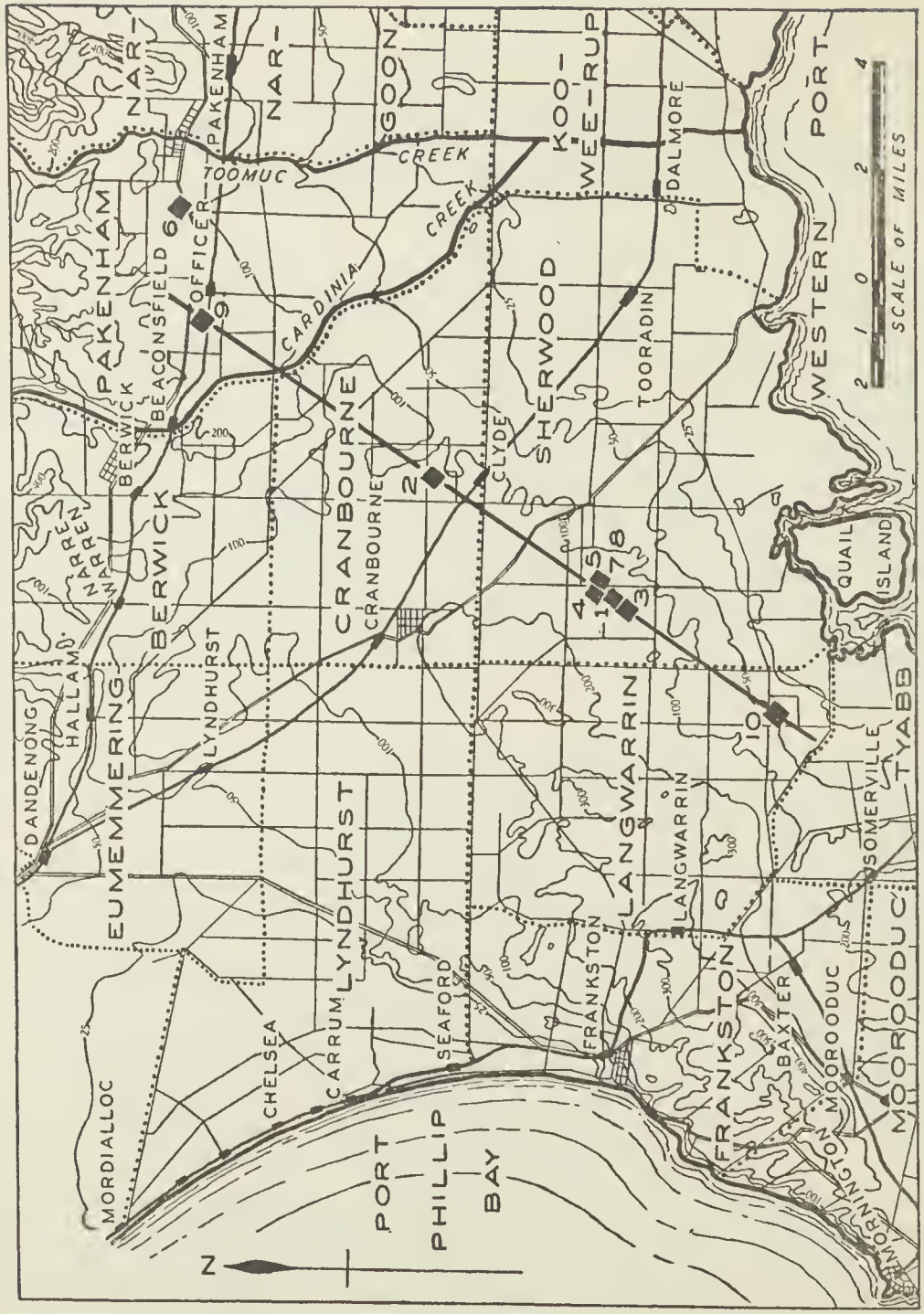


FIG. 1.

Sites of the Cranbourne group of Iron Meteorites. Compiled from the Lands and Survey county map of Mornington, 1919. Meteorite sites are indicated by full squares.

1, Cranbourne No. 1; 2, Cranbourne No. 2; 3, Cranbourne No. 3; 4, Cranbourne No. 4; 5, Cranbourne No. 5; 6, Pakenham (Cranbourne No. 6); 7, Cranbourne No. 7; 8, Cranbourne No. 8; 9, Beaconsfield; 10, Langwarrin.

The Cranbourne No. 3 iron was found half a mile from the Cranbourne No. 1 iron, on Carnmallam Pre-emptive Right, some time between 1854 and 1860. It weighed 15 lb. All trace of this iron has been lost, and there is no description of its composition or structure.

The Beaconsfield iron, weighing 165 lb., was found in 1876 in a railway cutting 2 miles east of Beaconsfield railway station, parish of Pakenham (Fig. 1). The main mass of this meteorite was bought for the Krantz collection, Bonn, Germany.

The Langwarrin iron was found in 1886, in allotment 94, parish of Langwarrin, 5 miles south-east of Langwarrin railway station, by Mr. A. H. Padley, who donated it to the National Museum, Melbourne. It weighed 18 cwt. when found, but has lost weight by rusting and scaling. Its present dimensions are 36 in. x 22 in. x 20 in.

Of the later-found meteorites, only the Pakenham iron (reported as Cranbourne No. 6 by Hodge Smith, 1939) has been described (Edwards and Baker, 1941). Its weight when found was 89 lb., and its size 12 in. x 7·5 in. x 6·5 in. This iron was found in 1928 on the south side of the Princes Highway, three-quarters of a mile west of Toomuc Creek, opposite allotment 14, parish of Pakenham (Fig. 1). Prior to its detailed description, Hodge Smith (1939) incorrectly reported the weight of this meteorite as 20 lb., and stated that it was in the National Museum collection, Melbourne, but the main mass is in the Victorian Geological Survey Museum (Reg. No. 8150). It now weighs 48 lb., the loss in weight being due to rapid scaling and to the removal of portions for chemical and mineralogical examination. It has been painted with colourless duco varnish to prevent further scaling.

Of the four Cranbourne meteorites found in 1923, No. 4 and No. 5 have been reported by Hodge Smith (1939), and so-named by him. The other two are here named Cranbourne No. 7 and Cranbourne No. 8.

The Cranbourne No. 4 iron was found on the property of Mr. G. Bacon, in allotment 34, parish of Sherwood. When found it measured 39 in. x 26 in. x 20 in., and weighed approximately 1·25 tons (not 10 cwt. as reported by Hodge Smith, 1939). It was bought by the Victorian Mines Department, and is stored in the basement of the National Museum, Melbourne.

The Cranbourne No. 5, the Cranbourne No. 7 and the Cranbourne No. 8 meteorites were found close together by Mr. A. R. Croker when ploughing in his paddock in allotment 33, parish of Sherwood (Fig. 1).

The Cranbourne No. 5 (Plate IV, Fig. 1) weighs 7 cwt. (not 6 cwt. as stated by Hodge Smith, 1939), and is now housed at the Victorian Mines Department drill store. When found it measured 27 in. x 18 in. x 18 in. As a result of scaling, its present dimensions are 24 in. x 18 in. x 15 in.

The Cranbourne No. 7 iron when found weighed about 3 cwt. and measured 22 in. x 13 in. x 12 in. It was donated by the Director of the Geological Survey to the Geology Department of the University of Melbourne in May, 1941. It has scaled badly, despite painting with aeroplane cement, and is now reduced to 16 in. x 12 in. x 9 in. (May, 1943). A piece weighing 3 lb. is in the Australian Museum, Sydney; this is recorded by Hodge Smith (1939) as a piece of Cranbourne No. 5, but it is a portion of Cranbourne No. 7. Cranbourne No. 5 has not been previously cut or drilled.

The Cranbourne No. 8 iron weighed 52 lb. when unearthed. A piece was sawn off for analysis and examination at the Victorian Mines Department, and the main mass, now weighing 46 lb., is preserved in kerosene at the Geological Survey Museum, together with a small etched piece (Plate IV, Fig. 3) weighing 2 lb. Its original size was about 8·5 in x 7·5 in. x 6 in.

As shown in Fig. 1, the four irons found in 1923 all lay close to the site of the Cranbourne No. 1 iron, three of them occurring close together in one paddock. The Pakenham iron, found in 1928, lay about 10 miles to the north-west of this group, close to the site of the Beaconsfield meteorite. With the exception of the Pakenham iron, all the sites lie on a straight line joining the Langwarrin and Beaconsfield sites, which are 13 miles apart. In view of Madigan's (1940) conclusion that the smaller members of a meteorite shower lag behind the larger, it would appear that the meteorite was moving south-westwards, since the smaller masses have been found in the north-east and the larger in the south-west.

Texture and Composition

Widmanstätten Structures

The four new Cranbourne meteorites, like the earlier described irons from this district, show coarse Widmanstätten structures (Plate IV, Figs. 2 and 3), and fall into Prior's category Og, i.e., coarse octahedrites (Prior, 1920). The bands of α-iron (kamacite) are from 1 mm. to 10 mm. wide, averaging about 4

mm., and are 4 mm. to 30 mm. long, averaging 12 mm. This is typical for the four meteoritic masses.

Neumann Lines

Neumann lines were observed in the α-iron of the Cranbourne No. 7 meteorite, on surfaces that had been flattened by filing, but not on surfaces ground flat with carborundum on a rotating lap. In this respect, the Cranbourne No. 7 iron resembled the Kyancutta iron (Spencer, 1933).

Chemical Composition

Analyses were made by one of us (A.B.E.) on the metal of the Cranbourne Nos. 4, 5 and 7 irons, using freshly prepared shavings (Table 1, analyses 6, 7 and 8). The shavings from the No. 4 and No. 5 irons were obtained by drilling the respective meteorites after de-scaling their surfaces and collecting the shavings with a magnet as they broke from the drill. The shavings from the No. 7 iron were obtained during the shaping of a sawn fragment in a Selson shaping machine. Care was taken in each instance to avoid including material from nodules. In addition, three unpublished analyses of the No. 8 iron (analyses 9, 11 and 12), including one of the metal free from nodule material (Table 1, analysis No. 9), were placed at our disposal by the Director of the Victorian Geological Survey, and six published analyses are added to Table 1 for purposes of comparison.

Analyses 1 to 9 reveal marked uniformity of composition in seven of the analysed irons, but the analyses of Cranbourne No. 1 and of the Beaconsfield iron give higher figures for nickel. Coarseness of Widmanstätten structure is closely controlled by the nickel content of the iron-nickel alloy (Edwards and Hodge Smith, 1941). Widmanstätten figures developed on Cranbourne No. 1 and the Beaconsfield irons show that they, like all the other members of the group, are coarse octahedrites; had their nickel contents been those indicated in the analyses, Cranbourne No. 1 would be a fine octahedrite and the Beaconsfield iron a medium octahedrite. It is therefore almost certain that the higher nickel shown in these two analyses is due to faulty sampling, and it may safely be assumed that the nickel contents of both meteorites is of the order of 6·5 per cent.

The relative abundance of sulphur and carbon in analysis No. 10 indicates that this sample of the Cranbourne No. 8 iron included material from a pyrrhotite-graphite nodule; analysis No. 11 was made from similar material. The analysis of the scale from this meteorite (analysis No. 12) shows that during the oxidation of

TABLE I.

CHEMICAL COMPOSITION OF CRANBOURNE METEORITES.

	1	2	3	4	5	6	7	8	9	10	11	12
Fe	91·08	92·34	92·56	92·28	92·31	92·38	92·33	92·81	92·80	85·63	86·40	55·59
Ni	8·11	6·38	7·34	6·24	6·81	6·87	6·78	6·51	6·89	6·98	6·31	3·96
Co	0·50	0·75	0·48	0·58	0·54	0·49	0·53	0·55	nil.	nil.	nil.	nil.
Cu	0·01	0·02	0·02	0·06	nil.	—	—	—	nil.	nil.	nil.	nil.
P	0·11	0·19	0·26	0·17	0·37	0·21	0·19	0·24	—	0·23	—	0·31
S	—	0·18	0·04	—	nil.	nil.	nil.	nil.	—	2·21	—	0·35
C	—	—	0·05	—	—	—	—	—	—	1·94	—	0·37
Cl	—	—	0·01	—	—	pr.	pr.	pr.	—	str. tr.	—	tr.
Mn	—	—	—	—	—	—	—	—	—	sl. tr.	—	nil.
H_2O	—	—	—	—	—	—	—	—	—	2·10	—	—
Insol.	0·17	—	—	0·32	nil.	tr.	nil.	nil.	0·12	0·20	0·41	12·58
Total	99·98	99·86	100·76	99·65	100·03	99·95	99·83	100·11	99·81	99·29	93·12	73·16
Fe/Ni	11·2	14·5	12·6	14·8	13·5	13·4	13·6	14·3	13·5	12·3	13·7	14·0
Sp. Gr.	7·46	—	—	—	7·93	7·5	8·12	7·98	7·64	—	7·24	—

1. Cranbourne No. 1. Anal. W. Flight. Phil. Trans. Roy. Soc. London, 173, pp. 885-894, 1882.
2. Cranbourne No. 2. Anal. P. G. W. Bayly and A. G. Hall. Mem. Nat. Mus. Melb., No. 6, 1915.
3. Beaconsfield. Anal. O. Sjostrom. *Ibid.*, quoted by R. H. Walcott, 1915.
4. Langwarrin. Anal. P. G. W. Bayly and A. G. Hall. *Ibid.*
5. Pakenham (= Cranbourne No. 6). Anal. A. B. Edwards. Pr. R. Soc. Vict., 54 (1), n.s., pp. 7-16, 1941.
6. Cranbourne No. 4. Anal. A. B. Edwards.
7. Cranbourne No. 5. Anal. A. B. Edwards.
8. Cranbourne No. 7. Anal. A. B. Edwards.
9. Cranbourne No. 8. Sample obtained by cutting through specimen with a hack-saw. Anal. F. F. Field.
10. Cranbourne No. 8. Sample obtained by filing across the cut face of the meteorite, avoiding scale. Clearly includes material from a sulphide-graphite nodule. Anal. F. F. Field. Quoted by Hodge Smith in Aust. Mus. Mem., No. 7, p. 54, 1939.
11. Cranbourne No. 8. Sample obtained by cutting metal with a hack-saw, and including some surface scale and a nodule. Anal. F. F. Field.
12. Cranbourne No. 8. Oxidized scale. Anal. F. F. Field.

the iron there has been little or no selective leaching or migration of the nickel relative to the iron, since the ratio of Fe/Ni is practically the same as that of the fresh iron. Presumably, therefore, the nickel has entered the composition of the limonite forming the scale.

Nodules

All the Cranbourne irons are characterized by the presence in them of numerous nodules. These have been found both in the iron (Plate IV, Fig. 2) and in the limonitic scale or crust. In the Cranbourne No. 2 mass, five nodules can be observed in the polished face of the iron, which has an area of 120 x 90 mm.; the largest of these nodules measures 30 x 20 mm. One in the Langwarrin iron measures 45 x 15 mm. Those found in the Cranbourne No. 8 vary from 12·5 x 12·5 mm. to 25·5 x 19 mm. The smallest nodule found was in the Cranbourne No. 7; it measures only 1 mm. across, and consists of graphite. Another graphite nodule from the same iron measures 14 x 15 mm.; the largest nodule, a composite one, measures 25 x 15 mm. The largest nodule from the Pakenham iron (Cranbourne No. 6) measures 40 x 30 x 21 mm., and weighs 45 grams. The largest recorded occurred in the Cranbourne No. 1 iron, and is 50 mm. across.

A few of the nodules have a sub-spherical shape, and a few are ellipsoidal, irregular, or bean-shaped, but the majority approximate to a triaxial ellipsoidal shape, with average dimensions about 14 x 9 x 6 mm.

The composition of the nodules varies somewhat. A few consist solely of graphite, or troilite, or of pyrrhotite, but the majority are mixtures of graphite and pyrrhotite. A few consist of mixtures of graphite and troilite. The majority have a rim of schreibersite (Plate IV, Fig. 4), and veinlets of limonite traverse cracks in the sulphides and sometimes intervene between the sulphide-graphite cores and the phosphide rims.

According to Flight (1882), the nodules in the Cranbourne No. 1 iron consisted of troilite surrounded by thin layers of graphite and daubréelite. The nodules in the Beaconsfield and Cranbourne No. 2 irons are also reported to consist of troilite and are said to decompose to stilpnosiderite (Walcott, 1915, p. 31). It is doubtful, however, that the sulphides in these nodules were tested by etching, and in view of the preponderance of pyrrhotite over troilite in the nodules so tested from the Pakenham and the four Cranbourne irons under discussion, it seems likely that some of the substance recorded as troilite may have been pyrrhotite.

Mineral Composition

As would be expected from their chemical composition, the four irons consist essentially of α-nickel-iron (kamacite), with minor amounts of γ-nickel-iron (taenite). Associated with the iron are minor amounts of various iron-nickel phosphides. In the nodules are found other phosphides together with graphite, pyrrhotite and troilite.

The oxidized crust or scale of the meteorites consists chiefly of limonite, with residual patches of nickel-iron metal and some of the phosphides, chiefly rhabdite. In places, trevorite is associated with it, and some of the scale exudes or is encrusted with small quantities of the chlorides of iron and nickel.

Nickel-iron Alloys

The α-nickel-iron (kamacite) is iron white and isotropic, strongly magnetic and readily scratched with a needle. The standard etching reagents affect it as follows: nitric acid produces an immediate etching, but without effervescence; hydrochloric acid fumes tarnish, and the iron washes and rubs brown, but the effect is not consistent; potassium hydroxide and potassium cyanide are negative; ferric chloride instantly turns the iron brown, bringing up grain boundaries and etching grains differentially, as well as bringing up Neumann lines; mercuric chloride darkens the surface immediately. Picric acid (2 per cent. in alcohol) and bromine water darken the kamacite and bring up grain boundaries and crystal structures.

The γ-nickel-iron (taenite) occurs only as occasional groups of parallel lamellae interleaved with the kamacite plates, and as small triangular areas in the interstices of the kamacite grains. It can scarcely be distinguished from the kamacite in unetched sections, but is readily distinguished after etching with picric acid, bromine water, or 2 per cent. nitric acid in alcohol, all of which darken the kamacite but do not affect the taenite. Of the standard etching reagents, nitric and hydrochloric acids, potassium hydroxide, ferric chloride and mercuric chloride give negative results. Hydrochloric acid fumes tarnish the taenite brown, but the results are not consistent. The taenite is isotropic, strongly magnetic, and is readily scratched with a needle.

The factors controlling the disposition of the taenite lamellae in the kamacite have been discussed elsewhere (Edwards and Hodge Smith, 1941).

Iron-nickel Phosphides

Four varieties of iron-nickel phosphides have been observed in the meteorites. In appearance, etching behaviour, and manner of occurrence, these varieties are identical with those found in the Pakenham meteorite, and figured in its description (Edwards and Baker, 1941).

Two of them, schreibersite and a yellow unidentified phosphide, occur associated together, forming rims around the sulphide nodules, the schreibersite being much the more abundant. They are not found away from the nodules. The others, rhabdite and schreibersite-B, occur in the nickel-iron and do not appear in the nodules.

The schreibersite is a tin-white, brittle, hard mineral that cannot be scratched with a steel needle, occurring as the outer rim of the nodules (Plate IV, Fig. 4). It is difficult to polish on account of its brittleness, is distinctly anisotropic and strongly magnetic. On treatment with nitric acid it effervesces very slowly, the bubbles rising from the numerous cracks in the surface. With potassium hydroxide it very slowly develops a brown stain that washes brown and rubs pale brown. The action may take several minutes to develop, and sometimes appears only after several applications of the reagent. This is presumably due to the difficulty of removing films of oil from the surface, the oil having entered the many cracks during polishing.

The yellow phosphide has a creamy-yellow colour and is readily scratched with a needle. It is isotropic and does not appear to be magnetic. It is negative to all etching reagents other than mercuric chloride, which slowly stains it a purplish brown. The stain washes the same colour and is difficult to rub off, when it leaves a roughened surface.

Rhabdite occurs as small rhombs and prisms disseminated through the massive kamacite. It is much harder than the enclosing iron, and cannot be scratched with a steel needle. It is brittle, brown by contrast with the iron, distinctly anisotropic and strongly magnetic. It is negative to all standard etching reagents.

Schreibersite-B occurs as occasional large irregular areas, the shapes of which are partly controlled by the octahedral structure of the iron, but chiefly as fine vein-like areas in the interstices of the α-nickel-iron crystals. It is extremely difficult to polish on account of its brittleness and hardness. It is weakly anisotropic and generally resembles the schreibersite in appearance, but its colour is almost identical with that of the rhabdite crystals in the adjacent iron crystals. Its behaviour with etching reagents

distinguishes it from both. Unlike schreibersite, it is negative to both nitric acid and potassium hydroxide, but with hydrochloric acid it effervesces slowly, the bubbles rising from the numerous cracks; and this distinguishes it from the rhabdite, which gives negative results.

The chemical composition of the four phosphides has been discussed in connection with the Pakenham meteorite (Edwards and Baker, 1941), and will not be repeated here.

Pyrrhotite and Troilite

These minerals occur only in the nodules. Both are creamy-brown in colour and strongly anisotropic, and they can be distinguished from each other only by their different etching behaviour. With nitric acid the surface of pyrrhotite is tarnished but washes clean, whereas troilite effervesces vigorously with the evolution of hydrogen sulphide. Hydrochloric acid fumes tarnish the surface of pyrrhotite but the acid does not otherwise affect it, whereas troilite effervesces vigorously with this acid and is stained brown. Of the other reagents, potassium cyanide, ferric chloride and mercuric chloride give negative results, while potassium hydroxide stains both brown.

Of these minerals pyrrhotite is more commonly present in the nodules than is troilite. The sulphides may form the whole of a nodule core, or they may be intergrown with graphite, when the proportion of graphite tends to be greater near the margin.

Graphite

Graphite was found chiefly in the nodules, but some occurs as flakes or patches in the limonitic coatings of the meteorites. In polished section it is strongly anisotropic in brownish-grey colours and is pleochroic. It is soft, brittle, inert to all etching reagents, and marks paper.

Oxidation Products

Many fragments of scale removed from the meteorites consist of unreplaced remnants of nickel-iron, sometimes several millimetres in diameter, cemented together by limonite. Such fragments have a hackly fracture, and when polished look like an iron-limonite breccia. Other pieces of the scale are sheet-like or lens-shaped, and consist essentially of limonite showing colloform banding. The limonite is studded with minute prisms and rhombs of rhabdite, indicating that the limonite has replaced the iron *in situ*. No trace of the schreibersite-B veins remains, so that presumably this mineral is destroyed by the lawrencite that the meteorites exude.

Occasionally a pinkish-brown mineral is intercalated with bands of limonite. It is isotropic and inert to etching reagents. The powder obtained with the micro-drill is distinctly magnetic, and yields positive tests for iron and nickel. The mineral is regarded, therefore, as trevorite.

The limonitic scale of the Cranbourne No. 4, No. 5 and No. 7 irons contains numerous quartz grains, and such grains have been recorded in the scale of Cranbourne No. 2 (Walcott, 1915). Both rounded and angular grains occur, imbedded in the scale to a depth of two or three inches. They apparently represent sand which has been blown against the meteorite, and adhered to it during the process of oxidation. The depth at which the quartz is found is some measure of the expansion that takes place during the oxidation and hydration of the iron.

Oxidation of the Cranbourne Irons

With the exception of the Cranbourne No. 2 iron, all these meteorites show a pronounced tendency to oxidize and scale, so that they are extremely difficult to preserve. The Cranbourne No. 1 iron in the British Museum is kept in an atmosphere of nitrogen on this account; and the Cranbourne No. 8 iron, in the Geological Survey Museum, Melbourne, is preserved in a bath of kerosene.

Oxidation is partly due to the composition of the irons, which contain insufficient nickel to enable them to resist rusting. The rapidity and depth of oxidation appears, however, to be connected with the presence of unusual amounts of chlorine (in the form of chlorides) in the interior of the meteorites. A freshly polished surface of iron, whether large or small, very soon exudes numerous droplets of ferrous chloride along the junctions of kamacite bands, along cracks, and at the junctions of nodules with the metal. One such prepared surface, 4·5 × 3·5 inches, developed strings of minute globules after standing overnight, and even when the specimen was immersed in kerosene, the globules continued to grow in size. As long as the specimen was maintained in kerosene, the liquid of the globules was prevented from attacking the iron, and when the specimen was tilted, the larger globules rolled off its surface. When, however, the surfaces of such specimens are left exposed to the atmosphere, the globules etch the polished surfaces and completely destroy the polish within a few days.

The globules are at first almost colourless and consist of ferrous chloride. On exposure to air they become yellowish and then brown as the ferrous chloride oxidizes to ferric chloride, which attacks the iron. After two or three days the ferric chloride

changes to colloidal ferric oxide, which dries up to form pustules of limonite in the course of a few weeks. Sometimes a little nickel chloride develops in this way, as was noted with the Pakenham meteorite (Edwards and Baker, 1941).

It is noteworthy that the Cranbourne No. 2 iron, which does not show this tendency to rapid oxidation and scaling, is similar in chemical composition to the irons that do oxidize; but, so far as has been noticed, it has not exuded more than a few droplets of iron chloride. This mass shows flight markings, and is therefore part of the exterior of the original large meteorite of which the several masses described herein are portions.

Farrington (1901, p. 402) has suggested that gases in meteorites were partly chemically united and partly probably held in intermolecular spaces. If the chlorine (or chloride content) is a primary constituent of the Cranbourne meteorites, then presumably it was expelled (or oxidized) in the surface layers of the original meteorite at the temperature attained during flight through the atmosphere and driven under pressure into the interior of the mass where it was retained in the interspaces between the kamacite lamellae.

Another possibility is that the chlorine (or chlorides) was introduced into the meteorites as they lay, almost completely buried, in the ground. The area in which they occurred is distinctly swampy during some periods of the year, as evidenced by the records of the Victorian Mines Department, and the subsoil is saline, carrying as much as 0·1 per cent. of sodium chloride (Holmes, Leeper and Nicolls, 1940). Many of the meteorite masses lay in the subsoil for not less than 70 years, and chlorides in the surface waters might have penetrated the iron along cracks and grain boundaries.

Acknowledgments

The authors are indebted to the Director of the Victorian Geological Survey Department, Mr. W. Baragwanath, for the photographs of Cranbourne Nos. 5 and 8 meteorites, for permission to use information from original correspondence in the Victorian Mines Department's files relating to the occurrence and history of Cranbourne Nos. 4, 5, 7 and 8 irons, and for additional data concerning the meteoritic masses. Our thanks are also due to the Director of the National Museum, Melbourne, Mr. D. J. Mahony, for granting us access to Cranbourne No. 4 meteorite, and for allowing us to use material from this mass for chemical and mineralogical investigations. Mr. G. Ampt and Mr. G. Leeper, of the Melbourne University Chemistry Department, kindly offered suggestions leading to the ideas relating to the probable origin of the chlorides in the meteoritic masses. We are grateful to Mr. A. Wilcock, of the Melbourne University Metallurgy Department, for cutting and shaping samples of Cranbourne No. 7 meteorite; to the personnel of the Victorian Mines Department Drill Store for

drilling samples from Cranbourne No. 5 meteorite, and to Messrs. A. H. Mackie and C. D. Macpherson for drilling the Cranbourne No. 4 meteorite.

Description of Plate IV

Fig. 1. External surface of Cranbourne No. 5 meteorite, showing size and shape of specimen and nature of the scaled surface. (Photo.—Victorian Mines Dept.)

2. Etched surface of Cranbourne No. 7 meteorite, showing coarse Widmanstätten structure and pyrrhotite nodule surrounded by schreibersite. Dark areas in centre of photograph are portions from which metal was plucked out along octahedral structures during preparation of the flat surface. (Photo.—J. Spencer Mann.)

3. Etched surface of Cranbourne No. 8 meteorite, showing coarse octahedral structure and pronounced kamacite bands. (Photo.—Victorian Mines Dept.).

4. Nodule of pyrrhotite with irregular rim of graphite and schreibersite, embedded in limonite; from Cranbourne No. 7 meteorite. (Photo.—J. Spencer Mann.)

References

Edwards, A. B., and G. Baker, 1941. The Pakenham Meteorite. Pr. R. Soc. Vict., 54 (1), n.s., pp. 7-16, 2 pl.

Edwards, A. B., and T. Hodge Smith, 1941. The Tawallah Valley Meteorite. Rec. Aust. Mus. 21, no. 1, pp. 1-8, 2 pl., 2 text figures.

Farrington, O. C., 1901. The Constituents of Meteorites, I. Journ. Geol., 9 (2), pp. 393-408.

Flight, W., 1882. Report on the Examination of the Meteorites of Cranbourne in Australia, of Rowton in Shropshire and of Middleborough in Yorkshire. Phil. Trans. R. Soc., London, 173, pp. 885-894, 1 pl.

Hodge Smith, T., 1939. Australian Meteorites. Austr. Mus. Mem. No. 7, 19 pl., 5 text figs.

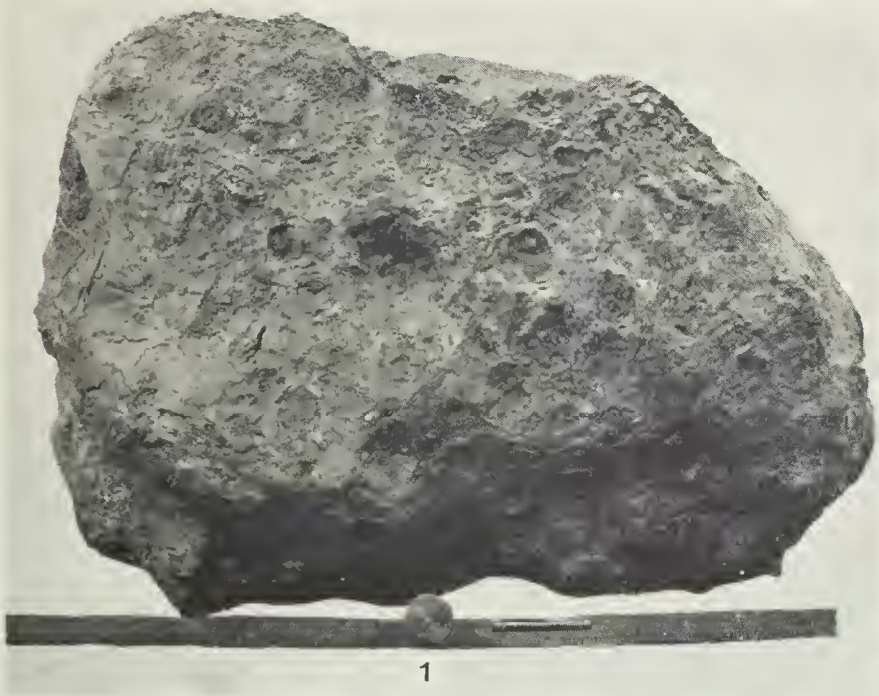
Holmes, L. C., G. W. Leeper and K. D. Nicolls, 1940. Soil and Land Utilisation Survey of the Country around Berwick. Pr. R. Soc. Vict., 52 (1), n.s., pp. 177-238.

Madigan, C. T., 1940. The Boxhole Meteoritic Iron, Central Australia. Min. Mag. 25, pp. 481-6.

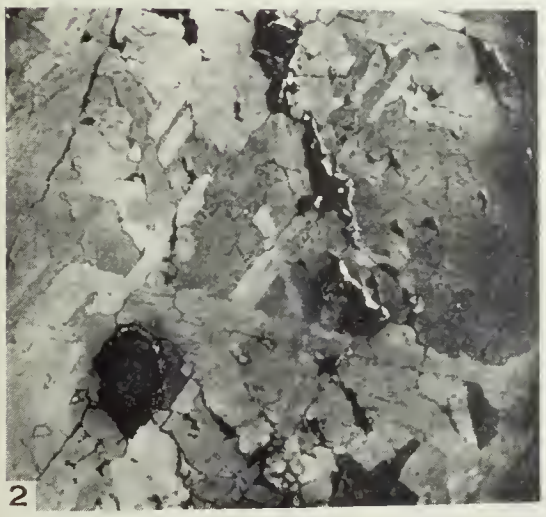
Prior, G. T., 1920. The Classification of Meteorites. Min. Mag. 19, pp. 51-63.

Spencer, L. J., 1933. A New Meteoric Iron found near Kyancutta, South Australia. Min. Mag., 23, pp. 329-333, 3 text figs.

Walcott, R. H., 1915. Description of the Victorian Meteorites with notes on Obsidianites. Mem. Nat. Mus., Melbourne, no. 6, pp. 63, 4 pl.



1



2

x 0·9

3

x 0·9

4

x 1·8

Cranbourne Meteorites

AN ARTEFACT, PROBABLY OF PLEISTOCENE AGE, FROM KEILOR, VICTORIA

By D. J. Mahony, M.Sc.,
Director, National Museum of Victoria.

Plate V.

Some 35 years ago Mr. G. Moreton Riley, the well known amateur telescope maker, noticed part of a large pebble protruding from a low cliff of silty clay on the right bank of the Maribyrnong River about 30 yards downstream from the mouth of its tributary Salt Creek (Green Gully), a mile south of Keilor as the crow flies; Keilor is 10 miles north-west of Melbourne. The pebble was about 5 ft. above the base of the cliff and 4 ft. below its top; and, since it was the only one visible in the fine-grained material, Mr. Riley forced it out and then saw that one end was flaked to form the cutting edge of a primitive axe or chopper.

In February of this year he brought the specimen to the Museum, and his description of the position where he found it suggested that it had been enclosed in a Pleistocene terrace deposit. In view of this, he kindly arranged to accompany Mr. R. A. Keble and Miss Hope Macpherson (who had mapped the terraces in this locality) and myself to the place. In the years that have elapsed since the implement was found, the river has cut back its right bank for some yards and has destroyed the original site, but Mr. Riley pointed out the corresponding position close by in the existing bank of similar fine-grained material.

The river hereabouts has cut its channel through Pleistocene flood-plain deposits (compacted silt with occasional layers of small rounded quartz pebbles) into the underlying Silurian strata, and the flood-plain deposits now form terraces on both its banks. Short descriptions of the three main terraces in the Maribyrnong River valley, namely, the Keilor, the Braybrook and the Maribyrnong Park Terraces, and evidence of their Pleistocene age have been published elsewhere (Mahony, 1943 b). The river bank from which the specimen came is part of the youngest of these, the Maribyrnong Park Terrace, the surface of which is here about 19 ft. above the river bed; Mr. Keble and Miss Macpherson have measured the levels in this locality and found

that the river bed is 25 ft. 6 in. and the surface of the terrace 44 ft. above low water mark at Williamstown. The Maribyrnong Park Terrace is somewhat younger than the Keilor Terrace in which fossil human skeletal remains were found (Mahony, 1943 a; Wunderly, 1943; and Adam, 1943).

The implement (Plate V) consists of a waterworn pebble of spotted hornfels with a curved, smooth cutting edge at its thinner end made by knocking off flakes from one side, the other side of the cutting edge being formed by the waterworn surface of the pebble. Weathering has equally affected both the whole waterworn surface and surfaces from which flakes have been removed, and it has partly obscured the sharp outlines of the latter; this suggests antiquity. As shown in the illustration, the pebble is flattened on one side and rounded on the other; about half way along the rounded side is a roughened, pitted area, measuring an inch by three-quarters of an inch, which may have been caused by percussion, such as hammering with a hard stone. Apart from flaking, the pebble retains its original shape.

Hornfels *in situ* does not outcrop near Salt Creek, but it does five miles northward in the Maribyrnong River (Deep Creek) valley at the contact of Palaeozoic strata with intrusive granodiorite (James, 1920).

A cast of the specimen is in the National Museum of Victoria.

References

Adam, Wm., 1943. The Keilor Fossil Skull: Palate and Upper Dental Arch. Mem. Nat. Mus., Melbourne, 13, pp. 71-77, 4 figs., 2 pl.

James, A. V. G., 1920. The Physiography and Geology of the Bulla-Sydenham Area. Pr. R. Soc. Vict., 32 (n.s.), pt. 2, pp. 321-49, 2 figs., 3 pl.

Mahony, D. J., 1943 a. The Problem of Antiquity of Man in Australia. Mem. Nat. Mus., Melbourne, 13, pp. 7-56, 7 figs., 3 pl.

1943 b. The Keilor Fossil Skull: Geological Evidence of Antiquity, *Ibid.*, pp. 79-81.

Wunderly, J., 1943. The Keilor Fossil Skull: Anatomical Description. *Ibid.*, pp. 57-69, 1 fig., 6 pl.

ADDENDUM

After the above notes were in print, Mr. K. F. Rose of the Meteorological Bureau presented to the Museum a stone artefact with a cutting edge which he had found in Hughes's sandpit, Keilor, where the fossil human skull was discovered. The implement when found was lying on the floor of the pit, evidently not in situ, but it may have been discarded during excavation of the Pleistocene terrace deposit. It is approximately three and a quarter inches long, two and a half inches at its widest end, and an inch thick. Like the implement described above, it is a hornfels pebble flaked only on one side, the other side being the natural surface of the pebble; and in technique, material and weathering the implements are similar.

Brown, Prior, Anderson Pty. Ltd.

Artefact from Junction of Green Gully and Maribyrnong River